

A Doppler-like strong light-matter interaction.

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Abstract

While complicated, unreliable alternatives to Doppler effect were proposed, an elementary optical light- matter interaction provides one which is commonly observed in the labs, but with a distortion due to the use of short, powerful laser pulses.

It is generally assumed that Raman scattering in gases is incoherent. This assumption fails if the pressure is lowered enough to increase the relaxation times over the length of light pulses; the "Impulsive Stimulated Raman Scattering" (ISRS), generally used to study dense matter with ultrashort laser pulses, is adapted to the low energy pulses making the incoherent light beams; the usual light is redshifted by some very low pressure gases while it propagates.

To produce this adapted ISRS called "Incoherent Light Spatially Coherent Raman Scattering" (ILSCRS), a molecule must have an hyperfine structure: polyatomic molecules must be heavy or have odd numbers of electrons; light atoms and the other molecules must be perturbed by a Stark or Zeeman effect.

ILSCRS redshifts may be distinguished from Doppler redshifts using a very difficult to observe dispersion of ILSCRS redshifts. This dispersion may explain the discrepancies of the fine structures in the spectra of the quasars, presently attributed to a variation of the fine structure constant.

While the present interpretation of the Lyman forest in the spectra of quasars requires clouds stressed, for instance, by sheets of dark matter, ILSCRS interpretation requires only usual physical concepts. It produces thermal radiations from short wavelengths, just as dust.

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1 Introduction

Twenty years ago, many astrophysicists thought that Doppler effect was unable to explain some observed redshifts. But they were unable to find a credible alternative because they introduced two restrictions:

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- They generally supposed that the electromagnetic field is sinusoidal. A consequence of this hypothesis is that if the received frequency is not equal to the emitted frequency, the number of wavelengths between the source and the receiver changes permanently, that is the distance between them changes, the frequency shift is a Doppler shift. Thus, looking for a non-Doppler frequency shift which would help the interpretation of some astrophysical data, Marmet [1] wrote that it is necessary to consider pulsed light; but the process he proposed is not convincing.

- They considered that individual molecules were involved in the interactions, while the molecules must be packed into sets in the theory of many optical effects, refraction, amplification in a laser,...

Unaware of astrophysics, working in pure optics, it appeared to us that an interaction of ordinary incoherent light with gases induces redshifts which may be confused with Doppler redshifts [2, 3, 4]; this interaction, although strong, seemed unobservable in the labs, requiring extremely low pressure gases, thus very long optical paths. This effect appears now as an avatar of the "Impulsive Stimulated Raman Scattering" (ISRS), commonly observed in the labs using ultrashort laser pulses.

This paper has two aims: - first, compared to the previous ones, it is a much more precise and, I hope, easier to read description of the new effect called "Incoherent Light, Spatially Coherent Raman Scattering" (ILSCRS); a short summary of the sections, at their beginnings, allows the reader to have an overview sufficient to follow the paper without studying the following demonstrations. - second, it gives the correspondence between ISRS and ILSCRS, setting precisely what happens when the short, powerful laser pulses replace the longer, weaker pulses which make the natural incoherent light. We hope that this connection between ISRS and ILSCRS will convince the astrophysicists of the reality of ILSCRS, so that they take it into account in their models.

The properties of pulsed light have been extensively studied using ultrashort, femtosecond laser pulses; compared to laser pulses, the pulses of incoherent light are longer by a factor of the order of 10^5 ; the definition of an "ultrashort pulse" was given by G. L. Lamb as "shorter than all relevant time constants" [5]; in a gas, for a Raman effect, these time constants are the time between collisions which may be increased by a decrease of pressure, and the period corresponding to the Raman transition which may be chosen long enough. Thus, the nanosecond pulses whose ordinary incoherent light is made of, are "ultrashort".

ISRS, described by Yan et al. [6], is mostly used to study fast evolutions of dense matter [7, 8, 9, 10, 11, 12]. The frequency shift is the result of an interference of the exciting beam with a Raman scattered beam. The emission of the scattered light is stimulated by the powerful exciting beam, so that the scattered amplitude is proportional to the square of the exciting field; thus the frequency shift depends on the intensity of the light; in ILSCRS the Raman scattered field is spontaneous, proportional to the exciting field, so that the frequency shift does not depend on the exciting field.

The summaries of the subsections are followed by more technical explanations and demonstrations, made as simple as possible using the semiclassical theory, following Bloembergen [13]: “The subtle interplay between real and imaginary parts of the complex linear and nonlinear susceptibilities follows quite naturally from the semiclassical treatment. [...] The semiclassical theory which is used in this monograph will describe all situations correctly in a much simpler fashion”.

Section 2 recalls the general properties of ISRS and adapts them to ILSCRS.

Section 3 gives some spectroscopic properties of gases subject to ILSCRS.

Section 4 suggests possible applications of ILSCRS in astrophysics: we do not intend to give reliable interpretations of astrophysical observations.

2 Properties of ISRS and ILSCRS

This section presents the properties of ISRS and the conditions which must be fulfilled to preserve these properties replacing short powerful laser pulses by incoherent light, getting ILSCRS.

2.1 Space coherence

With space coherence, the output wave surfaces belong to the family of the input wave surfaces, so that the images are sharp, without any blur. To get the space coherence, nearly no collision must happen during a light pulse; in ILSCRS, only low pressure gases work.

In the Huygens’ construction of the wave surfaces, each point of a particular wave surface is considered as a source; the envelop of the wavelets produced by these sources after a short time Δt is new wave surface. This construction may be extended replacing the Huygens’ sources by scattering molecules, but some modifications and conditions appear:

- the number of molecules, thus the number of scattered waves is not infinite, so that the building of a new wave surface is not perfect. The most important consequence is the incoherent Rayleigh scattering (blue of the sky) which perturbs the refraction; we will consider that the fluctuations of the molecular density are low, so that such effects may be neglected.
- the phases of the waves scattered by all molecules lying on a particular wave surface must be the same; the classical and quantum computations of the scattered waves are identical for all molecules, unless collisions introduce phase changes.

To obtain the space coherence, during a light pulse it must be almost no collision between the molecules. The mean time between two collisions in a gas of identical spherical hard molecules is:

$$\tau = \frac{1}{2Nd^2} \sqrt{\frac{m}{4\pi kT}} \quad (1)$$

where N is the number of molecules by unit of volume, d their diameter, m their mass and T the temperature. This mean time gives only an order of magnitude because the molecules are not hard particles, so that it is difficult to define a length considered as the diameter of a molecule.

In conventional Raman spectroscopy, using regular sources, for instance mercury vapour lamps, the Raman intensity is so low that the pressure of a studied scattering gas must be of the order of magnitude of the atmospheric pressure; as the pressure in the source (made of heavy atoms) is lower than the pressure in the studied gas, the mean time between collisions is shorter than the duration of the pulses of light (about 10 nanoseconds), so that conventional Raman scattering is incoherent.

The incoherence is widely responsible of the weakness of the conventional Raman scattering: : Set $a \exp(i\phi_j)$ the complex amplitude scattered into a point by a molecule number j ($j = 1 \dots n$, where n is the number of scattering molecules). The total scattered intensity is:

$$I = \left(\sum_j a \exp(i\phi_j) \right) \left(\sum_k a^* \exp(-i\phi_k) \right). \quad (2)$$

In an incoherent scattering process, the ϕ_j are stochastic so that the mean value of $\exp(i\phi_j) \exp(i\phi_k)$ is zero if j is not equal to k , else one; thus the total intensity is $I_I = naa^*$. In a coherent scattering process, supposing that the wave surface converges into an usual diffraction figure, at the centre of this figure all ϕ_j are equal, so that I takes the large value $I_C = n^2 aa^*$; out of the diffraction figure, the scattered amplitudes cancel if the fluctuations in the repartition of the molecules are neglected. In conclusion, the incoherent process scatters a very low intensity in all directions; the coherent process scatters a strong intensity which produces, if the wavelength are nearly the same, the same diffraction pattern than the incident beam. As in astrophysics, we will always consider wide beams, so that diffraction may be neglected.

In many places of the universe, the pressure is so low that the pulses of ordinary light, long of 10 nanosecond or less, may be said “ultrashort” by a comparison with the mean time between collisions; in these places, Raman scattering is space coherent.

2.2 Interference of the incident and scattered waves into a single wave

Consider a single Raman transition. In conventional or coherent Raman scattering, the frequency of the scattered light gets a shift corresponding to a molecular transition; for ISRS or ILSCRS the period corresponding to the Raman transition must be larger than the length of the pulses, so that the two space-coherent beams interfere into a single monochromatic beam whose frequency is intermediate; the frequency shift is proportional to the regular Raman shift and to the scattered amplitude; the width of the exciting line is not increased.

With incoherent light, the Raman transition must correspond to a radio-frequency, the gas must have hyperfine (or equivalent) populated levels.

In the theory of refraction, the incident field induces in each molecule a dipole which radiates a wave dephased of $\pi/2$. The incident and scattered light interfere into a single wave, generally late in comparison with the incident wave.

In the semi-classical theory of the Raman effect, the dipole induced by the incident field is coupled with the dipole which radiates the Raman wave; at the beginning of a light pulse, the dipoles are dephased of $\pi/2$, so that the phases of the incident and scattered fields are the same, modulo π . During the pulse, the phase changes because the dipoles have different frequencies.

The interferences of two different frequencies is often observed, for instance between the two beams of a Michelson interferometer, when one of the mirrors moves, producing a Doppler frequency shift. Show by an elementary computation that, if this phaseshift is lower enough than π , the sum of the incident and scattered fields is a single field having an intermediate frequency

The electric field in a pulse of light is the product of a slow varying electric field $E(t)$ giving the pulse shape by a sine function; for an exciting field of frequency ν_e the field may be written $E(t) \cos(2\pi\nu_e t)$ and a field scattered at a frequency ν_s by a thin layer of thickness L of gas, with the same polarisation and the same phase at the beginning of the pulse ($t = 0$) : $E(t)Lq \cos(2\pi\nu_s t)$, where the product Lq is a small dimensionless coefficient including the thickness L ; Lq will be a first order quantity; the sum of the two emerging fields is:

$$\begin{aligned} D &= E(t)(1 - Lq) \cos(2\pi\nu_e t) + E(t)Lq \cos(2\pi\nu_s t) = \\ &= E(t)(1 - Lq) \cos(2\pi\nu_e t) + \\ &+ E(t)Lq(\cos(2\pi\nu_e t) \cos(2\pi(\nu_s - \nu_e)t) - \sin(2\pi\nu_e t) \sin(2\pi(\nu_s - \nu_e)t)). \end{aligned} \quad (3)$$

Writing the Raman frequency $\nu_i = \nu_s - \nu_e$ and the length of the pulse t_0 , suppose

$$|\nu_i t_0| \ll \pi, \quad (4)$$

that is the Raman period is much larger than the length of the pulses; we may develop the corresponding trigonometric functions:

$$\begin{aligned} D &\approx E(t) \cos(2\pi\nu_e t) - 2E(t)Lq\pi(\nu_s - \nu_e)t \sin(2\pi\nu_e t) \\ &+ 2E(t)Lq(\pi(\nu_s - \nu_e)t)^2 \cos(2\pi\nu_e t) + (4/3)E(t)Lq(\pi(\nu_s - \nu_e)t)^3 \sin(2\pi\nu_e t). \end{aligned} \quad (5)$$

set:

$$\tan(\phi t) = 2Lq\pi(\nu_s - \nu_e)t = 2Lq\pi\nu_i t; \quad (-\pi/2 < \phi \leq \pi/2); \quad (6)$$

$$\phi \approx 2Lq\pi\nu_i \quad (7)$$

is a first order quantity.

$$\begin{aligned} D &\approx E(t)(\cos(2\pi\nu_e t) \cos(\phi t) - \sin(2\pi\nu_e t) \sin(\phi t)) / \cos(\phi t) + \\ &+ 2E(t)Lq(\pi(\nu_s - \nu_e)t)^2 \cos(2\pi\nu_e t) + (4/3)E(t)Lq(\pi(\nu_s - \nu_e)t)^3 \sin(2\pi\nu_e t). \end{aligned} \quad (8)$$

In a first order approximation :

$$D \approx E(t) \cos((2\pi\nu_e + \phi)t). \quad (9)$$

The waves interfere into a single wave within the pulse. Thus, in place of the emergence of a new line shifted of ν_i , the whole incident flux gets the slight frequency shift

$$\Delta\nu = \phi/2\pi = Lq\nu_i. \quad (10)$$

Using wide beams to neglect the diffraction, the intensity of the conventional coherent Raman effect is limited because the difference of the indices of refraction for the incident and scattered frequencies introduces a phase-shift of the beams scattered on two different wave surfaces: the beams scattered by far wave surfaces have various phases, their interference is partly destructive. As in ISRS there is a single frequency, a single beam, there is no limitation of the effect by the dispersion of the refraction.

With ordinary incoherent light, the period corresponding to the Raman transition must be longer than 10 nanoseconds: the molecule must have Raman transitions in the radio-frequencies domain, in practice the molecule must have an hyperfine structure.

Heavy molecules and atoms have a convenient hyperfine structure, but they are probably not abundant in the gaseous part of the universe. The nuclear spin hyperfine structures, for instance in H_2 , are not efficient; on the contrary, light polyatomic molecules having an odd number of electrons have hyperfine structures whose interactions with light are strong.

Hyperfine structures are induced in all molecules by Stark and Zeeman effects; the width of the structure, is often proportional to the field; if it is not too large, so that condition (4) remains true, the frequency shift is proportional to the square of the field.

2.3 Linearity of ILSCRS

In ISRS, the scattered amplitude is proportional to the square of the incident amplitude because it is stimulated by the exciting laser beam, so that the redshift is proportional to the intensity of the light beam and a complex spectrum is distorted. In ILSCRS, the spontaneously scattered amplitude is proportional to the incident amplitude, so that the frequency shift does not depend on the intensity, the spectra are shifted without distortion.

It seems to be a discrepancy for the amplitudes scattered in ISRS and ILSCRS. But in quantum electrodynamics, and in the correct semi-classical theory, a spontaneous emission is an amplification of the corresponding mode of the zero point field. Thus the electric field of the exciting beam is the sum of a zero point field \mathbf{E}_0 and the field \mathbf{E} of the old classical theory. The computation of ISRS shows that the scattered amplitude is proportional to $(\mathbf{E}_0 + \mathbf{E})^2$ that is to $(E_0 + E)^2$ because the amplification does not change the polarisation. As the power is large in ISRS, E_0 may be neglected, the scattered amplitude is

proportional to the square of the field defined either in the old or in the recent theories. On the contrary, in natural light E is much smaller than E_0 so that E^2 may be neglected; E_0 , the intensity of the zero point field is always cancelled; it remains $2E_0E$, proportional to E because, in the average, E_0 is constant.

There is no threshold, a well known property of ISRS. To obtain a redshift independent of the intensity in the laboratory, using short laser pulses, the beams must be enlarged and the peak intensity decreased to get an electric field only a little larger than the zero point field.

2.4 Elementary computation of the ILSCRS redshift.

A complete computation of the ILSCRS redshift requires the knowledge of the traces of the tensors of polarizability for all radio-frequency Raman transitions, for all exciting frequencies. For the molecules having an odd number of electrons, chemically reactive, these data are difficult to measure or compute. In a classical representation of the Raman excitation of a molecule, we assume that the excited dipole is strongly coupled to the radiating dipole, so that the ILSCRS scattering has the same order of magnitude than the scattering which produces the refraction.

An exciting electromagnetic field induces for each Raman transition i a scattered field proportional to an element of the tensor of polarizability; averaging this result for all orientations of the gaseous molecules, the scattered field is proportional to the trace β_i of the tensor of polarizability and has the same polarisation than the exciting field; thus, the electric field may be considered as a scalar.

The amplitude p_i of the dipole induced in an unit volume for a transition i is proportional to the incident electrical field and to the number N_i of molecules per unit of volume in the convenient state: $p_i = N_i\beta_iE$. The field scattered at the exciting frequency ν_e produces the refraction through P, N and α similar to p_i, N_i and β_i .

At the thermal equilibrium, N_i is deduced from a Boltzman factor B_i , so that the ratio of a Raman dipole, with respect to the refracting dipole is:

$$\frac{p_i}{P} = \frac{N_i\beta_i}{N\alpha} = \frac{B_i\beta_i}{\alpha}; \quad (11)$$

The ratios of scattered amplitudes are the same for a single molecule to any direction, or for a large set of identical molecules on an exciting wave surface to the initial direction of propagation¹.

$$\frac{q_i}{Q} = \frac{p_i}{P} = \frac{B_i\beta_i}{\alpha}. \quad (12)$$

Recall the elementary theory of the refraction index n with our notations: Set $E \cos(2\pi\nu t)$ the electric field of a wave of frequency ν as it reaches a thin

¹The relation between the coefficients in the two configurations requires the addition of Huygens' wavelets by a simple but tedious integration called "the optical theorem".

sheet of gas whose thickness L is a first order small quantity; the absorption through this sheet is neglected so that the output field is $E \cos(2\pi\nu(t - L/c))$; the Rayleigh scattered field being late of $\pi/2$, the total output field is:

$$E[\cos 2\pi\nu(t - L/c) + LQ \sin 2\pi\nu(t - L/c)] \approx E \cos[2\pi\nu(t - L/c) - LQ] \quad (13)$$

The refraction index n is obtained by an identification of this field with $E \cos 2\pi\nu(t - nL/c)$, giving $n - 1 = cQ/(2\pi\nu)$.

The dynamical dielectric constant ϵ which equals $1 + 4\pi N\alpha$ is nearly 1 in a dilute gas, so that its square root n equals $1 + 2\pi N\alpha$; thus:

$$n - 1 = 2\pi N\alpha = cQ/(2\pi\nu). \quad (14)$$

By equations 12 and 14:

$$Lq_i = LQB_i\beta_i/\alpha = 4\pi^2 NB_i\beta_i\nu L/c. \quad (15)$$

From equation 10, we get the shift:

$$\Delta\nu = \sum_i [\nu_i Lq_i] = 4\pi^2 N \sum_i [B_i\beta_i\nu_i] \nu L/c. \quad (16)$$

In a first order development B_i is proportional to ν_i , so that the contribution of transition i to the lineshift is proportional to ν_i^2 .

Consider [2, 3] a model molecule having a high energy level and two low lying levels of energies E_1 and E_2 , close enough to allow a series development of the exponent in the Boltzman factor, so that the difference of the populations in the low states is:

$$N_1 - N_2 = N(B_1 - B_2) = N \left[\exp\left(\frac{-E_1}{2kT}\right) - \exp\left(\frac{-E_2}{2kT}\right) \right] \approx N \frac{E_2 - E_1}{2kT} = N \frac{h\nu_i}{2kT}. \quad (17)$$

β_i is different from α because it requires a transfer of energy from the excited oscillator to the radiating one; but this transfer is generally fast, so that generally β_i and α have the same order of magnitude; thus, assume the rough approximation $\alpha = 2\beta_1 = 2\beta_2$. Equation 12 becomes $q_i = B_i Q/2 = -QE_i/(4kT)$ for $i = 1$ or 2 . From equations 10, then 14 the frequency shift is

$$\Delta\nu = L(q_1 - q_2) \frac{E_1 - E_2}{h} = -\frac{L}{4hkT} (E_1 - E_2)^2 \frac{\pi\nu}{c} (n - 1) = \frac{Lh\nu_i^2}{2kT} \frac{\pi\nu}{c} (n - 1). \quad (18)$$

Replace the index of refraction using the classical dispersion formula for a single spinless electron resonating at the high frequency F which correspond to a transition between a low and the upper molecular states :

$$\frac{\Delta\nu}{\nu} = \frac{\pi L(E_1 - E_2)^2}{2hckT} \frac{Ne^2}{8\pi^2 m\epsilon_0 F^2} = \frac{Lh}{2ckT} \frac{Ne^2}{8\pi m\epsilon_0} \left(\frac{\nu_i}{F}\right)^2 \quad (19)$$

where $\nu_i = \nu_1 = (E_1 - E_2)/h$ is the regular Raman frequency shift, e and m are the charge and the mass of the electron.

2.5 To an experimental measure of the parameters of ILSCRS

As the hyperfine structures are generally complex, it seems difficult to compute the parameters of ILSCRS, except, maybe for simple but important molecules such as H_2^+ . Is an experimental measure possible ?

The Raman transitions which produce ILSCRS or ISRS are selected by the length of the pulses; thus, to get the parameters of ILSCRS redshift by a single experiment, it is necessary to use either incoherent light, or laser pulses whose lengths reproduce the lengths of the pulses in natural light.

Some active molecules, such as NO are stable, but it seems difficult to build a low pressure multiple path cell long enough to obtain a measurable ILSCRS redshift. It appears much easier to measure ISRS redshifts, even using long pulses. The correlation between ILSCRS and ISRS which was shown in subsection 2.3 gives the parameters of ILSCRS from those of ISRS, using long pulses.

2.6 Dispersion

In a first approximation, the dispersion of the tensor of polarisability is neglected, so that the relative frequency shift $\Delta\nu/\nu$ does not depend on the frequency. Introducing the dispersion, it may be possible, but uneasy, to distinguish an ILSCRS redshift from a Doppler redshift.

The α and β_i in equation 16 are computed from tensors of polarizability which, in a first approximation, do not depend on the frequency of the exciting light. If the frequency of an exciting beam is nearly the frequency of a dipolar absorption, Raman scattering is said “resonant”, the scattered amplitude is large. A polyatomic molecule has a large number of relatively weak absorption lines, thus a large number of relatively weak ILSCRS resonances: it will be difficult to observe them. On the contrary, the atomic lines are strong and well separated in the spectrum: the detection of ILSCRS resonances will be easier on light atoms perturbed by a Zeeman or Stark effect.

Using natural light, a low pressure gas, the de-excitation of the gas pumped by a redshifting ILSCRS process cannot result from collisions; but, in radio-frequencies, the spontaneous emissions of light are weak. Thus, the ILSCRS redshifting process is limited by the molecular de-excitation processes which may be an amplification of low frequency electromagnetic field (which includes the spontaneous emission, considering the zero-point field), an ILSCRS blueshift of a low temperature² optical mode . . .

These simultaneous processes must be bound into a parametric interaction³: the active molecule appears as a sort of catalyst which helps a flood of energy from the hot modes which are redshifted to the cold modes. As the intensity of the parametric interaction is limited by its weakest component, that is the transfer of energy to the cold modes which does not depend on the frequency of the hot modes, the dispersion of the redshift is reduced.

²The temperature of an optical mode is defined from the Planck’s laws.

³ILSCRS and ISRS describe only a part of the parametric process; a good acronym would be too long !

3 Applications of ILSCRS in low pressure gases

This section presents consequences of ILSCRS interactions in low pressure gases.

3.1 Visibility of lines absorbed by an ILSCRS active gas

The linewidth of an absorption or emission line of a red-shifting gas equals the redshift: thus the line is weak, wide, it cannot be observed individually; the absorption by a set of lines may be confused with an absorption by dust.

The absorption of the gas, supposed homogenous, is generally represented by an absorption coefficient $k(\nu)$ verifying:

$$d\Phi(\nu, x)/\Phi(\nu, x) = k(\nu)dx \quad (20)$$

where $\Phi(\nu, x)$ is the flux of energy of a light beam of frequency ν propagating along an Ox axis.

Consider a light flux initially in a small spectral range near a frequency ν_0 . If there is, along the light path, a redshift having any origin, expansion of the universe or ILSCRS, the frequency of this flux scans the whole redshift; its local absorption is a function of its local frequency ν_x ; the total absorption from $x = 0$ to $x = X$ is

$$\Delta\Phi = \int_0^X k(\nu_x)dx \quad (21)$$

As ν_x varies continuously in the range of the redshift, the function $k(\nu_x)$ scans the spectrum; the sharpest lines get a width larger than the redshift : they cannot be observed individually; as they generally obscure the high frequencies more than the low frequencies, in a partial observation of a spectrum, their absorption may be confused with an absorption by dust. In a region where the density of electromagnetic energy is large, the correlated increase of thermal radiation by ILSCRS may seem due to an increase of the temperature of the dust.

3.2 Detection of a red-shifting gas

Resonances in a red-shifting gas introduce slight variations of the relative frequency shift of the lines of a spectrum; if the spectrum is rich, the positions of the resonances may be found with a precision sufficient to characterise the red-shifting gas.

Discrepancies observed in spectra of quasars may be ILSCRS signatures, rather than a consequence of a variation of the fine structure constant.

The frequency shift may be written:

$$d\nu = \frac{\rho\nu}{q}dx \quad (22)$$

where ρ is the density of the gas and q a parameter depending on the gas. Supposing that the composition of the gas is constant, the equation is integrated from the frequencies ν_i of lines emitted or absorbed at $x = 0$ to the frequencies ν_{io} observed at $x = X$:

$$\int_0^X \rho dx = \int_{\nu_i}^{\nu_{io}} q \frac{d\nu}{\nu} = \int_{\nu_j}^{\nu_{jo}} q \frac{d\nu}{\nu} = \dots \quad (23)$$

To explicit that q depends slightly on ν , set $q = q_0 + r(\nu)$ where q_0 is a constant, and the average of the small function $r(\nu)$ is zero. From equation 23:

$$q_0 [\ln(\frac{\nu_i}{\nu_{io}}) - \ln(\frac{\nu_j}{\nu_{jo}})] = \int_{\nu_i}^{\nu_{io}} r(\nu) \frac{d\nu}{\nu} - \int_{\nu_j}^{\nu_{jo}} r(\nu) \frac{d\nu}{\nu} = \int_{\nu_i}^{\nu_j} r(\nu) \frac{d\nu}{\nu} - \int_{\nu_{io}}^{\nu_{jo}} r(\nu) \frac{d\nu}{\nu} \quad (24)$$

Supposing that $\nu_i - \nu_j$ is small, $r(\nu)$ may be replaced by its mean value $m(\nu_i, \nu_j)$ between ν_i and ν_j , so that equation 24 becomes:

$$\ln(\frac{\nu_i}{\nu_{io}}) - \ln(\frac{\nu_j}{\nu_{jo}}) = \frac{2(\nu_j - \nu_i)m(\nu_i, \nu_j)}{q_0(\nu_i + \nu_j)} - \frac{2(\nu_{jo} - \nu_{io})m(\nu_{io}, \nu_{jo})}{q_0(\nu_{io} + \nu_{jo})} \quad (25)$$

Supposing that the frequency shift is purely Doppler, the first member of equation 25 is zero; Webb et al. [14] observed that it is non-zero and wrote that it is due to a variation of the fine structure constant. ILSCRS seems a simpler explanation. As all frequencies are known, equation 25 gives a relation between $m(\nu_i, \nu_j)/q_0$ and $m(\nu_{io}, \nu_{jo})/q_0$.

To study the resonances which appear if absorption lines lie on the intervals (ν_i, ν_j) or (ν_{io}, ν_{jo}) , it is necessary to distinguish what comes from one or the other interval. This seems possible by a statistical study if lots of lines are measured. The quasars spectroscopy seem particularly favourable because:

- observing similar quasars, sharp absorption lines are observed with many different redshift, so that the averages $m(\nu_i, \nu_j)$ and $m(\nu_{io}, \nu_{jo})$ are local and significant.
- the active gases are made of atoms, so that there are few absorption lines, thus few, separated resonances;
- these resonances are near known dipolar absorption lines, so that their observation will be a test of the appropriateness of the theory for the quasars. Unhappily, up to now, we could not get the good spectra which show discrepancies in the hypothesis of pure Doppler effect.

3.3 Multiplication of absorption lines in a variable magnetic field

Light atoms do not have strong hyperfine transitions: they do not redshift the light, so that their absorption lines are visible; but if there is an electric or magnetic field, the redshift appears, the absorption disappears. Thus, for a light ray propagating in a variable magnetic field, lines are written as pseudo-lines into the light where the field is nearly zero, shifted when the field appears, written

Figure 1: Shapes of pseudo-lines (see text).

into an other place for another zero of the field, ... Each pseudo-line is sharp, although it has strong feet.

Consider a plasma of atoms at a temperature of 10 000K, with low enough a pressure to produce ILSCRS redshifts.

The ratio of the populations in two levels defining a low energy Raman transition, $\exp(h\nu_i/kT)$ at the equilibrium, may be developed, because the temperature is high; thus, the difference of B_i for a Stokes and its antiStokes interaction is proportional to $h\nu_i/kT$, so that, by eq.16, $\Delta\nu/\nu$ is proportional to $\sum_i[\beta_i\nu_i^2]$.

Usually, the ν_i are proportional to a field H ; define a variable x proportional to the mass of gas passed by the light beam through a unit of surface. As the frequency shift is proportional to the squares of the ν_i , thus to the square of the magnetic field, we may write:

$$d\nu = AH^2(x)dx, \quad (26)$$

where A depends on the nature and the physical state of the gas. The variation of flux by unit of surface $\Phi(\nu, x)$ is related to an absorption coefficient $K(\nu, x)$:

$$d\Phi(\nu, x) = \Phi(\nu, x)K(\nu, x)dx. \quad (27)$$

Equation 26 may be integrated numerically to get ν as a function of x , then equation 27 is integrated. Set ν_a the absolute frequency of a studied absorption line, x_n a value of x for which $H = 0$ and $X = x - x_n$; mark a spectral element of the light by its frequency f for $X = 0$. Suppose now that the absorption is low and that the linewidth is purely Doppler, so that without a field we would have the absorption at a frequency ν :

$$d\Phi(\nu) = -\exp(-a(\nu - \nu_a))^2 dx \quad (28)$$

equation 26, written with a convenient coefficient b becomes, for X small:

$$d\nu/dX = bX^2. \quad (29)$$

Integrating

$$\nu = bX^3/3 + f. \quad (30)$$

From equations 28 and 30 the variation of the intensity of the spectral element is:

$$d\Phi(f) = -\exp(-a(bX^3/3 + f - \nu_a)^2)dX \quad (31)$$

A numerical computation of Φ shows [4] that the half intensity width is nearly constant, so that, taking into account in the spectrum only the fast changing intensities, that is neglecting the feet of the lines, the pseudo lines appear as sharp as an ordinary line for the same temperature.

4 Tentative applications to astrophysics.

4.1 Order of magnitude of the redshifts.

The evaluation of a redshift requires a measure or a computation of parameters which are unknown, difficult to measure or compute. A rough evaluation is made demonstrative, computing the density of molecules which would produce a shift equal to the cosmological redshift.

In previous papers, we had computed an order of magnitude of the redshift using equation 19; this computation required an hypothesis about the ratio of frequencies ν_i/F , whose evaluation is arbitrary. We prefer now to use equation 18 because it uses the index of refraction of a gas which has the same order of magnitude (5.10^{-4} in the normal conditions) for all gases, and the Raman frequencies ν_i , more variable, but which have often many possible values, up to the limit frequency, about 100 MHz; the highest frequencies have the largest contribution.

We will consider that all ILSCRS active scatterings have nearly the same amplitude than the coherent Rayleigh scattering which produces the refraction; this hypothesis leads probably to an under-evaluation because, as the pulses are short, the numerous Raman oscillators are resonant with the excited oscillator, quickly excited.

For a moderate redshift, Hubble's law is

$$\frac{\Delta\nu}{\nu L} = \frac{1}{L} \sqrt{\frac{c - LH_0}{c + LH_0}} - \frac{1}{L} \approx \frac{H_0}{c} \quad (32)$$

Combining it with equation 18:

$$\frac{c\Delta\nu}{\nu L} = H_0 = (n - 1) \frac{\pi h \Sigma_i \nu_i^2}{2kT} \quad (33)$$

$n - 1$ is proportional to the density of molecules N , so that, using an index 0 for the normal conditions, R being the constant of the perfect gases:

$$N = N_0 \frac{n - 1}{n_0 - 1} = \frac{10^3}{22.4} \frac{2H_0 R T}{\pi h (n_0 - 1) \Sigma_i \nu_i^2} = 3,58.10^{35} \frac{H_0 T}{(n_0 - 1) \Sigma_i \nu_i^2} \quad (34)$$

With $H_0 = 2,5.10^{-18}$, $T = 2,7K$, $n_0 - 1 = 5.10^{-4}$ and $\Sigma_i \nu_i^2 = 10^{16}$, the number of molecules required to get the whole cosmological redshift from ILSCRS would be 5.10^5 molecules per cubic meter, in the average.

The detection of the 0,21 m forbidden line shows that there is some H_2 molecules in the cold regions of the space; the UV radiation of the stars photoionizes H_2 into H_2^+ which is ILSCRS active; where the pressure is low so that the time between collisions is large, H_2^+ is stable, the proportion of H_2 molecules transformed into H_2^+ should be large.

4.2 The spectra of quasars

The flexibility of ILSCRS interactions allows a lot of hypothesis ...

In the spectra of the quasars, the most shifted lines are emission lines whose shifts decreases with the frequency; this decrease could be explained supposing that the hardest X rays, then UV, have a longer path in a redshifting gas. The broad absorption lines are absorbed in a colder, more external gas, thus their shift is lower. The emission lines may be sharp, coming from a relatively high pressure gas in which the redshifting is low, while the absorption is perturbed by a simultaneous frequency shift.

The Lyman absorption forest seems to be produced along the light path by intergalactic clouds generally close to galaxies [15, 16]; the dynamical or magnetic proposals to get these clouds thin enough to obtain a low Hubble line stretching do not seem to work, so that the clouds seem to be stressed by sheets of dark matter [17, 18, 19].

ILSCRS allows to consider that the clouds are thick, but that absorption leaves a visible pattern only where a magnetic field is nearly zero. The absorption by the remainder of the clouds is spread in the spectrum, it may produce a part of the absorption attributed to dust failing a better explanation [20] and in despite of the difficult survival of dust [21].

5 Conclusion

The “incoherent light impulsive stimulated Raman scattering” plays surely a role in the redshift of the astrophysical spectra; it is difficult to evaluate this role precisely, but it seems able to help the interpretation of observations.

Other interactions of very low pressure gases with light should be studied too, for instance the cooling of the gases or the decrease the coefficients of absorption of the spectral lines by loss of coherence, leading to an under-evaluation of the gas density.

I hope that some astrophysicists will find this paper useful, allowing the introduction of interesting topics for their research.

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